

Radial structure of galactic stellar disks

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Abstract. We present the results from our deep optical imaging survey $\mu_{\text{lim}}^V \approx 26 - 27 \text{ mag}/\square''$ of a morphologically selected sample of 72 edge-on disk galaxies. The question of the global structure of galactic stellar disks, especially the radial surface brightness profile at large galactocentric distances, is addressed. We find that typical radial profiles are better described by a two-slope exponential profile —characterised by an inner and outer scalelength separated at a break radius— rather than a sharply-truncated exponential model. Results are given for three face-on equivalents, serving as the crucial test to assure the findings for the edge-on sample without possible geometrical line-of-sight effects.

1. Introduction

Van der Kruit (1979) initially found that the outer parts of disks of spiral galaxies do not retain their exponential light distribution to the observed faint levels, but rather show sharp edges. For three nearby edge-on galaxies (NGC 4244, NGC 4565, NGC 5907) he derived that the typical radial scalelength h steepens from 5 kpc to about 1.6 kpc at the edge of the disk. The existence of these truncations, which are already visible in contour maps of edge-on and even of some face-on galaxies, is now well accepted (Pohlen 2001), but no unique physical interpretation is given to describe this observational phenomenon. The proposed explanations span a rather wide range of possibilities. Van der Kruit (1987) deduced a connection to the galaxy formation process describing the truncations as remnants from the early collapse. Ferguson & Clark (2001), for example, proposed an evolutionary scenario represented by the viscous disk evolution models. And Kennicutt (1989) suggested a —probably less striking— star-formation threshold. Up to now the applied characteristic parameter for comparing the observational results of different studies is the distance independent ratio of a truncation radius R_t to a measured radial scalelength h . Van der Kruit & Searle (1982) found for their sample of seven galaxies a value of $R_t/h = 4.2 \pm 0.6$, whereas Pohlen, Dettmar, & Lütticke (2000a) derived a significantly smaller one of $R_t/h = 2.9 \pm 0.7$ for their CCD survey of 30 galaxies.

2. Our new edge-on sample

To explain these different R_t/h values, we have improved the rather inhomogeneous sample of Pohlen et al. (2000b). The resulting morphologically se-

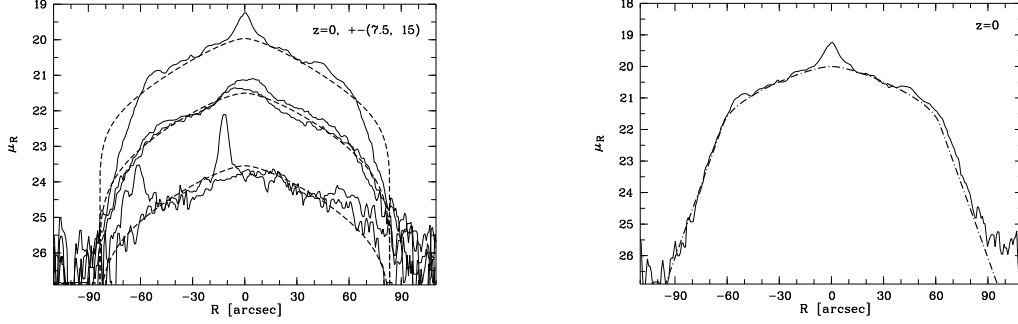


Figure 1. Radial surface brightness profiles (*solid lines*) of NGC 522 (*left panel*) together with the best fitting sharply-truncated model (*dashed line*) and the best fitting two-slope model (*right panel*).

lected sample contains 72 galaxies of high data quality. They are selected to be edge-on, undisturbed, and similar to ‘well-behaved’ disk-prototypical cases such as NGC 4565 and IC 2531. Thereby we want to assure that we are able to consistently fit our simple one-component disk model. We have chosen S0-Sd galaxies (mainly Sb-Sc) and have obtained deep optical imaging in at least one filter, reaching a limiting surface brightness of $\mu_{\text{lim}}^{1\sigma} \approx 26 - 27$ V-mag/ \square'' or $\mu_{\text{lim}}^{1\sigma} \approx 25 - 26$ R-mag/ \square'' .

We have fitted three different kind of models to the data (cf. Pohlen 2001): A sharply-truncated exponential model characterised by the cut-off radius R_{co} and the corresponding scalelength h_{co} . The cut-off radius is derived at the position where the profiles bend vertically into the noise. An infinite-exponential model, which is only characterised by a scalelength h_{∞} and realised by fixing the cut-off radius to ten times the sharply-truncated scalelength, to address the problem of the a priori assumed sharp truncations. And finally a two-slope or smoothly-truncated model, characterised by a break radius R_{br} and an inner h_{in} and an outer h_{out} scalelength, which is obtained by fitting two 1D exponentials to the profiles.

3. Results

A surprising result is that sample galaxies, although morphologically selected to look as similar as our simple model disk, frequently show significant deviations from the input model. Some objects exhibit a huge low surface brightness envelope (e.g. ESO 572-044,) or a rather perturbed outer component (e.g. UGCA 250). In another case (e.g. ESO 443-042) a strong bar hampers a reasonable model fitting. We find that three galaxies (NGC 3390, NGC 3717, NGC 4696C), classified as Sb, do not show a truncation feature in their radial surface brightness profiles, but rather an S0-like outer component. For the remaining galaxies we derive a mean value of $R_{\text{co}}/h_{\text{co}} = 3.5 \pm 0.8$ and confirm the suspected coupling of the two parameters, cut-off radius and associated scalelength, for the sharply-truncated model. This is, in combination to a slightly different way in identifying the cut-off radius, the reason for the significantly deviant results of van der Kruit & Searle (1982) and Pohlen et al. (2000a).

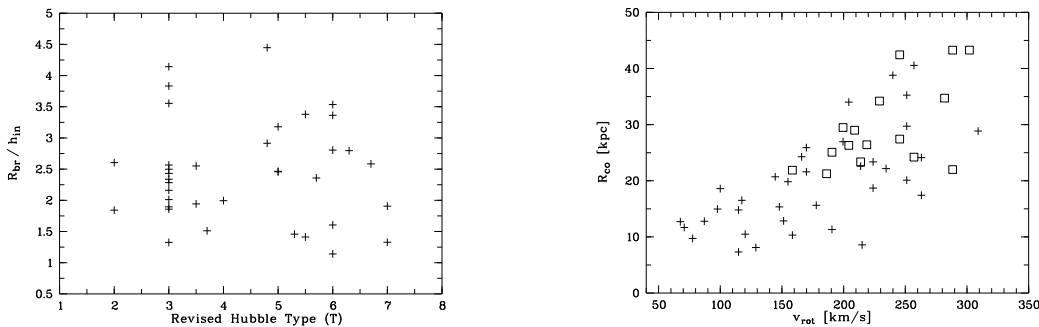


Figure 2. *Left panel:* Distribution of the distance independent ratio of R_{br} to h_{in} with Hubble type T (37 galaxies). *Right panel:* The distribution of cut-off radii versus maximum rotation velocity v_{rot} above square and below cross $D=50$ Mpc (52 galaxies).

The main result, however, is that most galaxies ($>60\%$) are best fitted with a two-slope or smoothly-truncated model. Fig. 1 clearly shows that the best fitting sharply-truncated model does not fit well for the inner profiles, which exhibit more likely a two-slope behaviour. The second slope is well described by another exponential decline. We derive for the distance independent ratio of the break radius to the inner scalelength a value of $R_{\text{br}}/h_{\text{in}} = 2.5 \pm 0.8$ (cf. Fig. 2) with mean values of 7.6 kpc for the inner and 1.9 kpc for the outer scalelength. The mean extrapolated surface brightness of this break on the major axis is $\mu_{\text{br}} = 23.4 \pm 0.6$ V-mag/ \square'' and $\mu_{\text{br}} = 22.6 \pm 0.6$ R-mag/ \square'' . Additionally, 35% of the galaxies are also well fitted at higher z -profiles with the two-slope structure. We want to emphasise that the profiles show a rather sharp break, but are not sharply truncated, implying that beyond the break we still find a remaining disk. These two-slope profiles could not be produced by any conventional dust distribution as simulations have shown. The various characteristic parameters (e.g. $R_{\text{co}}/h_{\text{co}}$, R_{co}/h_{∞} , $R_{\text{br}}/h_{\text{in}}$) do not correlate with the Hubble type, whereas plotting R_{co} and R_{br} in linear units versus the maximum rotation velocity reveals an unusual distribution (cf. Fig. 2). A general trend is expected since the faster the galaxy rotates the more mass it has and therefore its size will also be larger. However, there is a surprisingly sharp limit in the size-velocity relation apparent. Above a well defined diagonal line no galaxies are found, whereas there is no similar lower boundary for the expected diagonal. This would imply the existence of a maximal possible size for a given rotational velocity.

The crucial experiment to confirm this two-slope structure is to observe the same behaviour for face-on galaxies. We have used the 2.2 m telescope at Calar Alto with CAFOS and obtained images ($t_{\text{exp}} \approx 180$ min) of three face-on galaxies, chosen to be as circular as possible and therefore intrinsically face-on and not of early type. Observations are made using an efficient rectangular R-band filter (Röser R, RR) achieving a reliable photometry down to $\mu_{\text{RR}} = 28.0$ mag/ \square'' , equivalent to $\mu_{\text{JR}} = 28.4$ mag/ \square'' in Johnson R. We find that the azimuthally averaged profiles as well as profiles from individual sectors exhibit a similar two-slope structure (cf. Fig. 3). The break radius occurs at the same surface brightness level ($\mu_{\text{br}} = 24.9 \pm 0.6$ JR-mag/ \square'') as compared to the edge-on case, if the line of sight integration is taken into account. However, we derive a mean

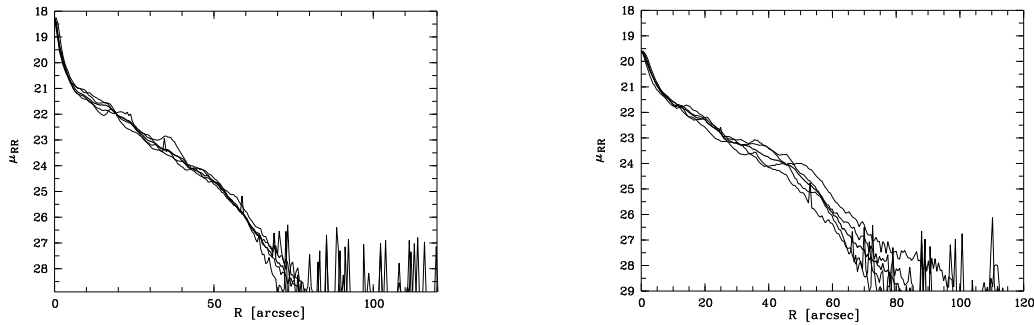


Figure 3. Azimuthally averaged radial surface brightness profiles (*solid lines*) of NGC 5923 (*left panel*) and UGC 9837 (*right panel*). Plotted are the four 90°-segments (*thin lines*) and the 360° (*thick line*) combined profile.

value for the ratio of the break radius to the inner scalelength $R_{\text{br}}/h_{\text{in}} = 3.9 \pm 0.7$ (individually: 4.3, 4.2, and 3.1) for the three galaxies. This does not fit well to the edge-on result and we probably still have a problem to find a good scalelength comparison for the edge-on and face-on case. However, the neglected dust and the applied 1D fitting of the individual scalelengths in the edge-on case both tend to increase the measured scalelength and therefore decrease $R_{\text{br}}/h_{\text{in}}$.

4. Outlook

After this extensive optical imaging campaign the physical nature of disk truncations is still unknown and will be approached in the next step. We are still lacking of a detailed analysis to prove that these truncations in the optical light profiles are also present in the mass distribution. In addition, one has to check for possible environmental effects to address a tidal truncation scenario. We will observe the radial molecular gas distribution —as the reservoir for star-formation— of galaxies with known optical truncations to find a correlation between the truncations and star-formation. A similar approach will be performed by a comparison study of the truncated optical profiles with $\text{H}\alpha$ -profiles tracing the actual star-formation.

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